CLAIMS

WHAT IS CLAIMED IS:

1. A method of analyzing trace metals in solution, comprising:

providing a sample channel separated from a carrier solution channel by an ion exchange membrane;

flowing a sample through the sample channel, wherein the sample includes a matrix and at least one trace metal to be detected;

providing an electrical potential to assist diffusion of ions through the ion exchange membrane; and

flowing a carrier solution through the carrier solution channel so that a component of the carrier solution is diffused through the ion exchange membrane into the sample channel to treat the sample for detection of the at least one trace metal.

2. The method of Claim 1, wherein the component of the carrier solution includes a metal-complexing reagent.

3. The method of Claim 2, wherein the sample is treated by forming a metal complex between the metal-complexing reagent and the at least one trace metal to be detected.

4. The method of Claim 2, wherein the metal-complexing reagent is an organic or inorganic acid.

5. The method of Claim 2, wherein the metal-complexing reagent is selected from the group consisting of formic acid, acetic acid, oxalic acid, glycolic acid, ethylenediaminetetraacetic acid (EDTA), nitrotriacetic acid (NTA), diethylenetriaminepentaacetic acid (DTPA),

ethylenediamine (EDA), glycine, iminodiacetic acid (IDA), and amines.

6. The method of Claim 1, further comprising detecting the stabilized trace metal by mass spectroscopy.

7. The method of Claim 1, further comprising flowing a carrier solution including hydroxide or hydronium ions through the carrier solution channel so that the hydroxide or hydronium ions are diffused through the ion exchange membrane into the sample channel to substantially neutralize an acidic or basic matrix.

8. A method of analyzing trace metals in solution, comprising:

providing a sample channel between two carrier solution channels, the sample channel being defined by two ion exchange membranes that separate the sample channel from the two carrier solution channels;

flowing a sample through the sample channel, wherein the sample includes a matrix and at least one trace metal to be detected;

providing an electrical potential between the carrier solution channels to assist diffusion of ions through the ion exchange membranes;

flowing a carrier solution including at least one metal-complexing reagent through at least one of the two carrier solution channels so that the at least one metal-complexing reagent is diffused through at least one of the ion exchange membranes into the sample channel;

forming a metal complex between the at least one metal-complexing reagent and the at least one trace

metal to stabilize the at least one trace metal in solution, thereby treating the sample; and

detecting the stabilized trace metal in the treated sample.

9. The method of Claim 8, wherein the metal-complexing reagent is an organic or inorganic acid.

10. The method of Claim 8, wherein the metal-complexing reagent is selected from the group consisting of formic acid, acetic acid, oxalic acid, glycolic acid, ethylenediaminetetraacetic acid (EDTA), nitrotriacetic acid (NTA), diethylenetriaminepentaacetic acid (DTPA), ethylenediamine (EDA), glycine, iminodiacetic acid (IDA), and amines.

11. The method of Claim 8, wherein the electrical potential is provided by an anode electrode and a cathode electrode in electrical communication with the two carrier solution channels.

12. The method of Claim 8, wherein the detecting of the stabilized trace metal is performed by mass spectroscopy.

13. The method of Claim 8, further comprising flowing a carrier solution including hydroxide or hydronium ions through at least one of the two carrier solution channels so that the hydroxide or hydronium ions are diffused through at least one of the two ion exchange membranes into the sample channel to substantially neutralize an acidic or basic matrix.

14. The method of Claim 8, wherein water is flowed through the at least one of the two carrier solution channels and electrolyzed to generate hydroxide or hydronium ions.

15. The method of Claim 8, further comprising re-flowing the treated sample through the sample channel for further treatment prior to analysis.

16. The method of Claim 15, wherein the treated sample is stored in a heated reservoir prior to being re-flowed through the sample channel.

17. The method of Claim 15, wherein the electrical potential is provided by an anode electrode and a cathode electrode in electrical communication with the two carrier solution channels.

18. The method of Claim 17, wherein the polarity of the electrodes are switched between re-flow cycles of the treated sample through the sample channel.

19. The method of Claim 8, further comprising recycling unspent metal-complexing reagent through the at least one of the two carrier solution channels.

20. The method of Claim 8, further comprising flowing a different carrier solution through each of the two carrier solution channels.

21. The method of Claim 20, wherein the carrier solution flowing through a carrier solution channel includes a metal-complexing reagent and the carrier solution simultaneously flowing through the other carrier solution channel does not include a metal-complexing reagent.

22. The method of Claim 8, wherein the ion exchange membranes are different from one another.

23. The method of Claim 8, wherein the ion exchange membranes are selective for ion-type and/or chemical group.

24. A method of analyzing trace metals in solution, comprising:

providing an electrodialysis apparatus including a sample channel between two carrier solution channels, the sample channel being defined by two ion exchange membranes that separate the sample channel from the two carrier solution channels;

flowing a sample through the sample channel, wherein the sample includes a matrix and at least one trace metal to be detected;

providing an electrical potential between the carrier solution channels transverse to the flow of the sample through the sample channel to assist diffusion of ions through the ion exchange membranes;

flowing a carrier solution including at least one metal-complexing reagent through at least one of the two carrier solution channels so that the at least one metal-complexing reagent is diffused through at least one of the two ion exchange membranes into the sample channel;

forming a metal complex between the at least one metal-complexing reagent and the at least one trace metal to stabilize the at least one trace metal in solution, thereby treating the sample;

flowing a carrier solution including hydroxide or hydronium ions through at least one of the two carrier solution channels so that the hydroxide or hydronium ions are diffused through at least one of the two ion exchange membranes into the sample channel to substantially neutralize an acidic or basic matrix, thereby treating the sample; and

analyzing the treated sample by mass spectroscopy to detect the stabilized trace metal.

25. The method of Claim 24, wherein the ion exchange membranes are different from one another.

26. The method of Claim 24, wherein the ion exchange membranes are selective for ion-type and/or chemical group.

27. An apparatus for analyzing trace metals, comprising:

a sample source that provides a sample including a matrix and at least one trace metal to be detected;

a carrier solution source that provides a carrier solution including at least one metal-complexing reagent;

an electrodialysis apparatus operably coupled to the sample source and the carrier solution source, the electrodialysis apparatus including a sample channel separated by at least one ion exchange membrane from at least one carrier solution channel;

a first electrode and a second electrode in electrical communication with the sample channel and the at least one carrier solution channel;

a reservoir operably coupled to an outlet of the sample channel for storing a quantity of treated sample prior to re-flow through the sample channel; and

an analyzer operably coupled to the reservoir for detecting the at least one trace metal in the treated sample.

28. The apparatus of Claim 27, wherein the sample channel includes a wall made of platinum.

29. The apparatus of Claim 27, further comprising heating means for heating the reservoir prior to re-flow of treated sample through the sample channel.

30. The apparatus of Claim 27, wherein the heating means includes a heater, a thermocouple, and a heater controller.

31. The apparatus of Claim 30, wherein the heater includes a heating blanket.

32. The apparatus of Claim 27, further comprising polarity changing means for switching the polarity of the electrodes between cycles of re-flow of treated sample through the sample channel.

33. The apparatus of Claim 32, wherein the polarity changing means includes a controller, a power supply, and polarity switching circuitry.

34. The apparatus of Claim 27, wherein the electrodialysis apparatus further comprises a second ion exchange membrane separating the sample channel from a second carrier solution channel, the at least one ion exchange membrane and the second ion exchange membrane defining therebetween the sample channel.

35. The apparatus of Claim 27, wherein the at least one ion exchange membrane is in the form of a cylinder and the sample channel and carrier solution channel are either of circular or annular cross-section.

36. The apparatus of Claim 34, wherein the at least one ion exchange membrane and the second ion exchange membrane are different from one another.

37. The apparatus of Claim 34, wherein the ion exchange membranes are selective for ion-type and/or chemical group.

38. The apparatus of Claim 27, wherein the analyzer includes a mass spectrometer.

39. The apparatus of Claim 38, wherein the analyzer includes an ionization apparatus for vaporizing and ionizing liquids prior to introduction to the mass spectrometer.

40. The apparatus of Claim 27, further comprising means for reflowing treated sample back through the sample channel.

41. The apparatus of Claim 27, further comprising means for reflowing the carrier solution back through the carrier solution channel.